A RUTTING DETERIORATION MODEL FOR PAVEMENTS IN THE JAPANESE MOTORWAYS

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ABSTRACT

Pavement maintenance and rehabilitation in mid and long term periods must be planned economically and effectively. In this doing, it is a critical factor to analyze and evaluate the life cycle cost of the pavement.
This paper describes a pavement deterioration model for network level in the Japanese motorways, based on surface characteristics and pavement repair inventory having been accumulated in the pavement management system (PMS) for the motorways.
Based on the rutting data and repair history for 12 years in a certain route from the PMS, a rutting deterioration model was developed using a multi-stage exponential hazard model combing the Markov transition probability.
Using this model, the factors that influence the process of deterioration were analyzed and commented.

1. INTRODUCTION

Construction, operation and maintenance of the nationwide toll motorways have been under the control of three companies, namely East, Central and West NEXCO's, since the previous main body of Japan Highway Public Corporation was privatized in 2005. Since JHPC was established in 1956, deterioration of all the road asset properties including pavements, structures, facilities and others has been increasingly concerned.

Therefore, it has been strongly requested how to keep those properties always in a good condition within a limited budget. Especially in the pavement field, a mid/long-term pavement management should be planned economically and effectively.

On behalf of the NEXCO's, Nippon Expressway Research Institute has been studying how to develop a deterioration forecasting model for a network level.

In this paper, based on the rutting data and repair history, a rutting deterioration model was developed using a multi-stage exponential hazard model combing the Markov transition probability. This is to report the result of the rutting deterioration model.

2. PURPOSE

To examine a mid/long-term repair strategy of pavement in consideration of life cycle cost, the purpose of this study is to evaluate applicability of a deterioration forecasting model.

One of the problems in developing the model is that deterioration process of pavement is not constant. Figure-1 is a distribution of rutting by elapsed time with 34,130 data which were measured every 100m in Kanetsu Expressway. The rutting data is variously distributed throughout the elapsed time. This is because not only traffic load but also type of road structure and weather influences the deterioration process of pavement. Therefore it is difficult to find a consistent relation between rutting increase and elapsed time. However it is considered to be able to predict rutting increase by applying a statistical method. In this study rutting increase models using a multi-stage exponential hazard model combing the Markov transition probability were developed.

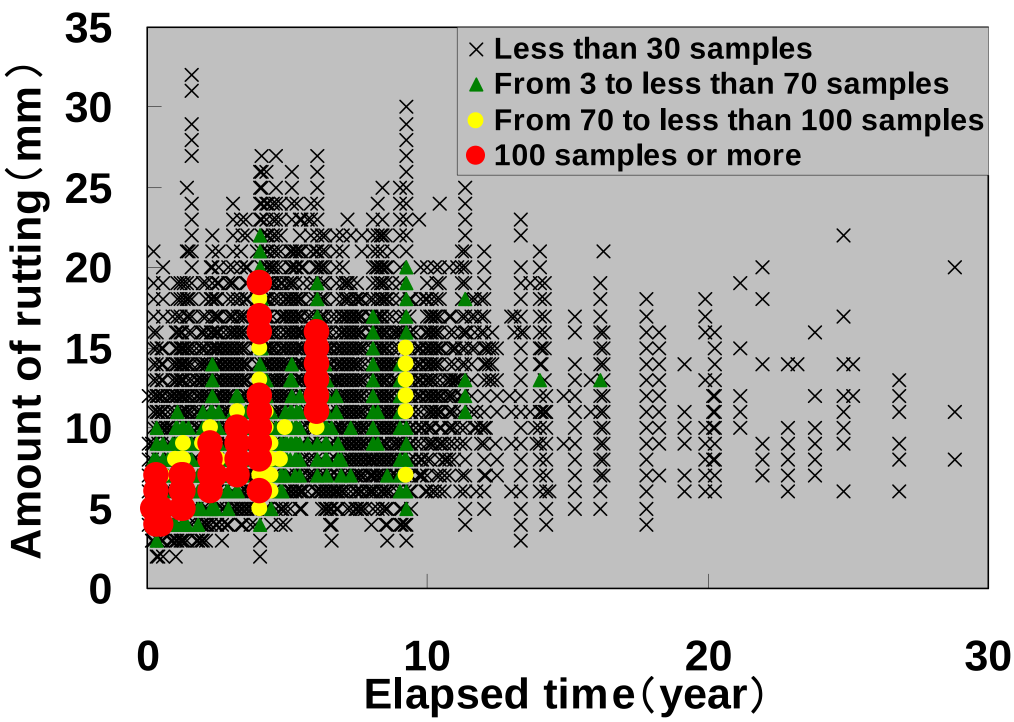

Figure-1. Elapsed time and amount of rutting (Kanetsu Expressway)

3. ROLE OF DETERIORATION FORECASTING MODEL

Figure-2 is an image of deterioration process. A repair standard here is assumed to be a rutting amount 25mm. T_0 is the time just after repair and T_2 is the time just before repair, while T_1 is a mid-time. Pattern of data to be obtained from site to site varies. Site A covers three data at the times of T_0, T_1, and T_2. Site B covers only two data at T_0 and T_1, while Site C also does two data at T_1 and T_2.

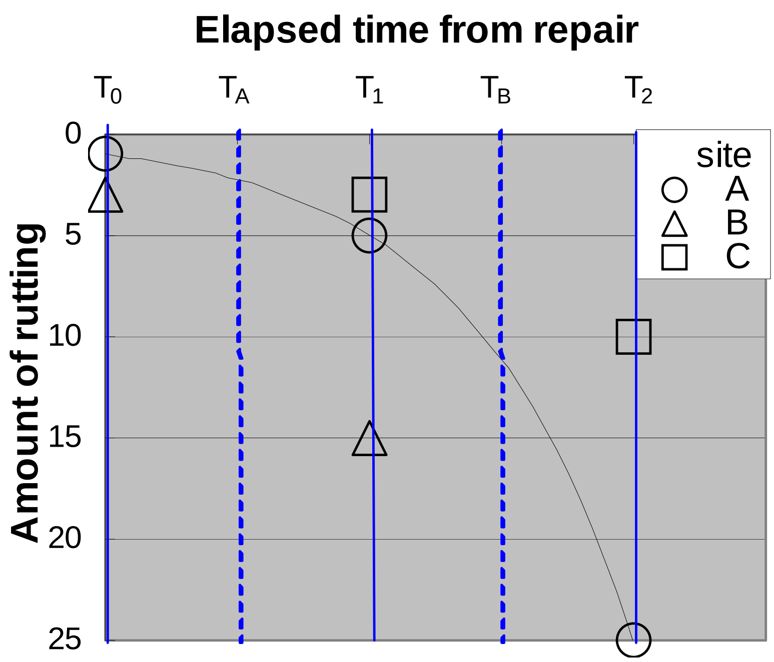

Figure-2. Deterioration process of amount of rutting

Site A can easily show a rutting increase curve until reaching a repair standard. Although it is rather difficult to make it for Site B and Site C, most of data actually comes from sites like the two sites. Therefore the Markoff transition probability procession is to be used for the development of a rutting increase model. This is because it is possible to predict rutting increase only from two data in time series, according to the theory.

In actual road survey, measurement is not always done at constant time intervals like T_0, T_1 and T_2. It may also be done at T_A and T_B. A rutting increase curve may then be changed at different time series. Therefore in order to deal with data at different time series, a multi-stage exponential hazard model combing the Markov transition probability was adopted.

Then, the performance curve as an example in Figure-3 is to be obtained by using the multi-staged exponential hazard model. The performance curve can be made if there are two data in different time series.

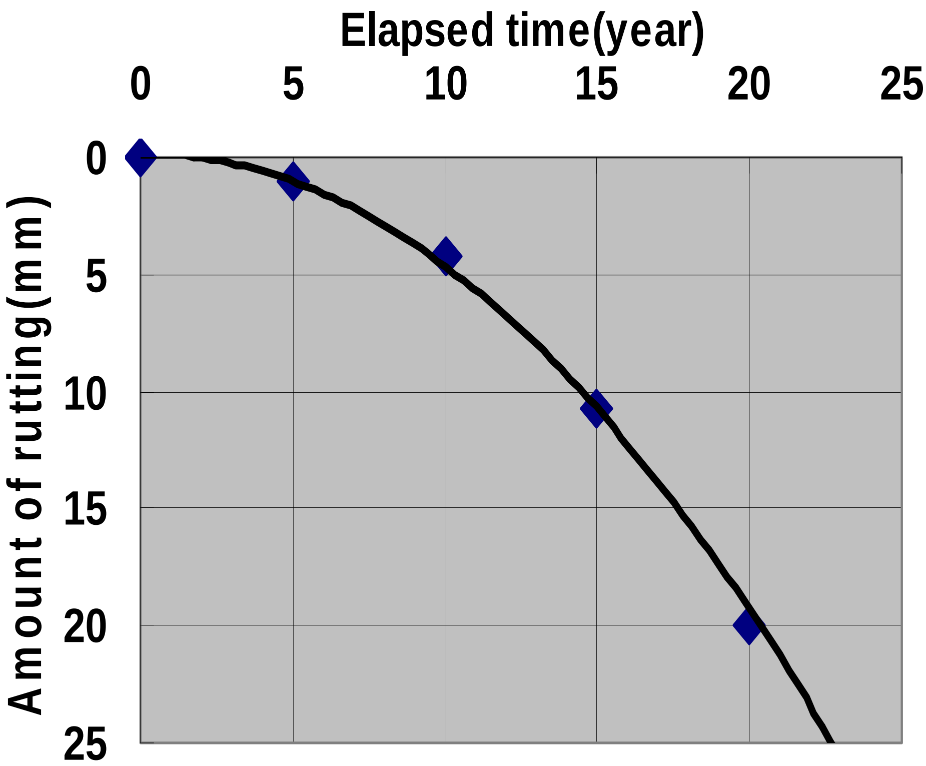

Figure-3. Example of performance curve

4. DATA SAMPLE FOR MAKING MODEL

It is important to preserve the quality of data sample as one of the necessary things to do for the deterioration forecast of pavement.

4.1 Data Site Information

The section of data as shown in Figure-1 is about 100km from Nerima IC to Takasaki IC of Kanetsu Expressway with four lanes and six lanes sections. It is approximately 30 years since the entire 100km sections were opened. The air temperature ranges from 0 to 30 degree centigrade. The types of road structure are embankment, bridge and tunnel. The annual average daily traffic is 50,000 to 100,000.

The reason of selection of this section is that repair history is considerably understood, and also that there are a lot of measured rutting data.

4.2 Raw Data

In this paper, the sample was made from data with two characteristics. One is measured rutting data and the other is repair history data.

4.2.1 Measured rutting data

Rutting measurement was continuously conducted from 1989 to 2001. The total lane length of the measurement is 4897.6km. Rutting data was obtained every 100m. Therefore the number of total data is 48,976 data, as shown in Table-1.

Inbound-outbound line	Lane number	Distance	Year of measurement											Total
			1989	1991	1993	1994	1995	1996	1997	1998	1999	2000	2001	
inbound	slower	0.1					0.1							0.1
	first	141.0	100	100	100	100	100	109	48.9	92.1	48.9	141	48.9	989.0
	second	92.1			56.6	73.7	73.7	90.9		80.9		90.8		466.6
	passing	141.0	100	100	100	100	100	106	48.9	92.1	48.9	141	48.9	986.0
out bound	slower	7.2	7.1	7.4	7.2	7.2	7.1		7.1		7.2	7.2	7.2	64.7
	first	141.0	100	100	100	100	100	141	48.9	92.1	48.9	100	48.9	979.5
	second	92.1			10.4	74.5	74.5	91.3		91.3		90.2		432.2
	passing	141.0	100	100	100	100	100	141	48.9	92.1	48.9	100	48.9	979.5
Total(km)		755.5	407	407	474	555	555	679	203	541	203	670	203	4897.6

Table-1. Rut measurement data by road surface investigation (km)

4.2.2 Repair history data

Repair history data was collected the same period as rutting data from 1989 to 2001. The total lane length of the repair history is 2178.8km.

4.3 Sample Making

4.3.1 Method of sample making

The sample necessary for the development of rutting forecasting model is made using two rut data between two time series.

A sample is usually made from road surface measurement data. One sample is correctly made from measurements of two data with two time series. (Table-2 sample 1) However, when rutting is decreased like sample 2, it should be deleted because it was thought that there was an influence of measurement error etc.

Table-2. Road surface measurement data

Route name	Inbound-outbound line	Lane classific-ation	Distance signpost (km)		Measurement fiscal year				
			For Nerima	For takasaki	1989	1991	～	2000	2001
Kanetsu	Outbound	first lane	0.0	0.1	5	9	～	12	10

(sample 1: 1989–1991; sample 2: 2000–2001. Attribute data: Route name through Distance signpost; Rut data by survey: Measurement fiscal year)

Another sample is made from repair history and road surface measurement data. The rutting after repair activity was regarded as 0mm, as shown in Table-3.

Table-3 Repair history and road surface measurement data

Route name	Inbound-outbound line	Lane classific-ation	Distance signpost (km)		Measurement fiscal year				
			For Nerima	For takasaki	1989 M	1991 R	～	2000 R	2001 M
Kanetsu	Outbound	second lane	30.7	30.8	12	0	～	0	9

(sample: 2000 R – 2001 M)

"M" stands for measurement, while "R" for that of repair.

Table-4 shows a combination of data made by the above two methods.

Table-4. Combination data

Route name	Inbound-outbound line	Lane classific-ation	Distance signpost (km)		Measurement fiscal year				
			For Nerima	For takasaki	1989 M	1991 M	～	2000 R	2001 M
Kanetsu	Outbound	first lane	50.0	50.1	5	10	～	0	9

(sample: 1989 M – 1991 M; sample: 2000 R – 2001 M)

4.3.2 Number of samples

The number of all samples made above is 41,990 samples. Because of not much data for concrete pavement, the pavement was excluded (Concrete: 352 samples).

The classification of samples for asphalt pavement is shown in Table-5. Because only two years have passed since porous asphalt was constructed, the pavement was also excluded. Therefore the other dense surface type was adopted with 34,130 samples.

Table-5. The classification of samples for asphalt pavement

Classification		Number of samples	Notes
Lane classification	slower lane	523	
	first lane	18272	
	second lane	6218	
	passing lane	16625	
structure	embankment	37282	
	bridge	4286	
	tunnel	70	
surface course	Asphalt（porous）	7508	Construction after 1999 years
	Asphalt（others）	34130	

4.4 Soundness Rating

A rutting forecast is done using the multi-staged exponential hazard model. In this model rutting data was converted into rating value (Hereafter, it is called, level of "Soundness".). This time, soundness was classified into five rank stages shown in Table-6. In the motor ways in Japan, 25mm is adopted as a level of criteria for repair. However when rutting value exceeds 20mm, the planning for repair activity is usually done. Therefore rank 5 that is the maximum rating of soundness is set 20mm or more.

Table-6. Soundness rating

Rank	Amount of rutting
1	Less than 5mm
2	From 5 to less than 10mm
3	From 10 to less than 15mm
4	From 15 to less than 20mm
5	20mm or more

5. ESTIMATION OF RUT FORECASTING MODEL

Rutting performance curve was developed using the sample mentioned in 4.3.

5.1 All Samples

The performance curve presumed by the multi-staged exponential hazard model is shown in Figure-4. Time from "Prior soundness" to "Post soundness" for every rank is here called a life expectancy.

- #1 The deterioration between ranks 1 to 2 is the earliest, and the expectation was 1.1 years.
- #2 The deterioration speed tends to slow with the increase of rutting, and it takes 23.5 years to reach rank 5.

rank	1→2	2→3	3→4	4→5	Total
Life expectancy (year)	1.10	6.83	6.81	8.73	23.47

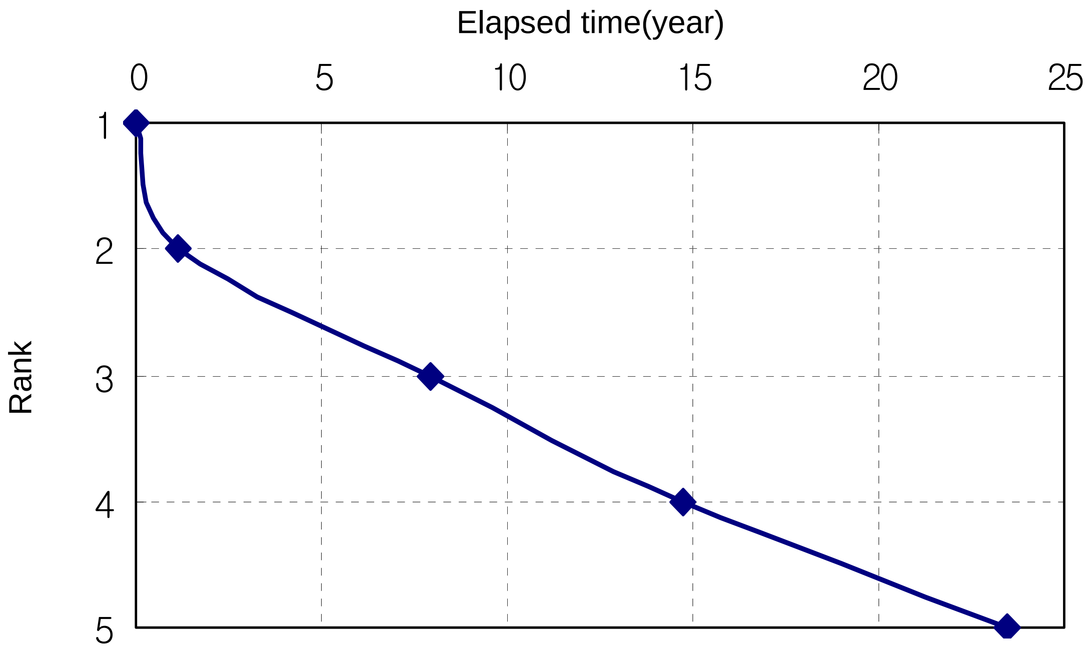

Figure-4. Performance curve of all samples

The reason for #1 is that an initial value of rutting in the field is actually not 0mm. The pavement cannot be completely flat after repair. Moreover, when vehicle tires pass, deformation by the load is to take place after the time of repair until that of measurement. This is why the shift speed from soundness rank 1 to 2 must have been quickened by these factors.

It is thought that the reason for #2 is that samples with increase of rutting will decrease. Table-7 covers a combination of prior soundness and post soundness.

The number of samples with post soundness deteriorated is going to be fewer less than that with prior soundness. Especially when prior soundness is two, there are extremely few samples with post soundness to change to 4 or 5.

The reason why the number of deteriorated samples decreases is that the pavement is to be repaired when deterioration proceeds. Road surface measurement is usually done without any relation to the repair activity. Therefore the amount of the rutting between "After measurement" and "At the time of repair" cannot be measured. Especially, the number of samples with “4 or 5 of post soundness” will decrease easily if rutting is increased fast during the time.

In this way decrease of sample at ranks 4 and 5 may influence accuracy of rutting forecast.

Table-7. Transition probability matrix

soundness		**Post soundness**				
	Rank	**1**	**2**	**3**	**4**	**5**
Prior soundness	**1**	**1283**	**7265**	**3046**	**1224**	**411**
	2		**9475**	**4087**	**211**	**100**
	3			**4299**	**1814**	**175**
	4				**602**	**203**

5.2 Each Structure

Figure-5 compared performance curves for each structure. Because there are few samples for tunnels, deterioration speed of embankment was compared with that of bridge.

The following results were obtained, although seemingly unrealistic.

- #3 The deterioration speed of bridge is almost the same as embankment.
- #4 It takes 24 years to reach rank 5.

#3 should be further investigated in the future. In general, it is thought that deterioration speed is different between embankment and bridge. It is uncertain whether the reason for this result is "Peculiar tendency to the route," "Influence of the limited number of bridge samples" or "Others". Therefore in order to find a reason, this model needs to be applied to another route nearby.

The result of #4 is almost the same tendency as #2

	rank	1→2	2→3	3→4	4→5	Total
Life expectancy (year)	embankment	1.13	6.76	6.81	8.73	23.43
	bridge	0.92	7.27	6.81	8.73	23.73

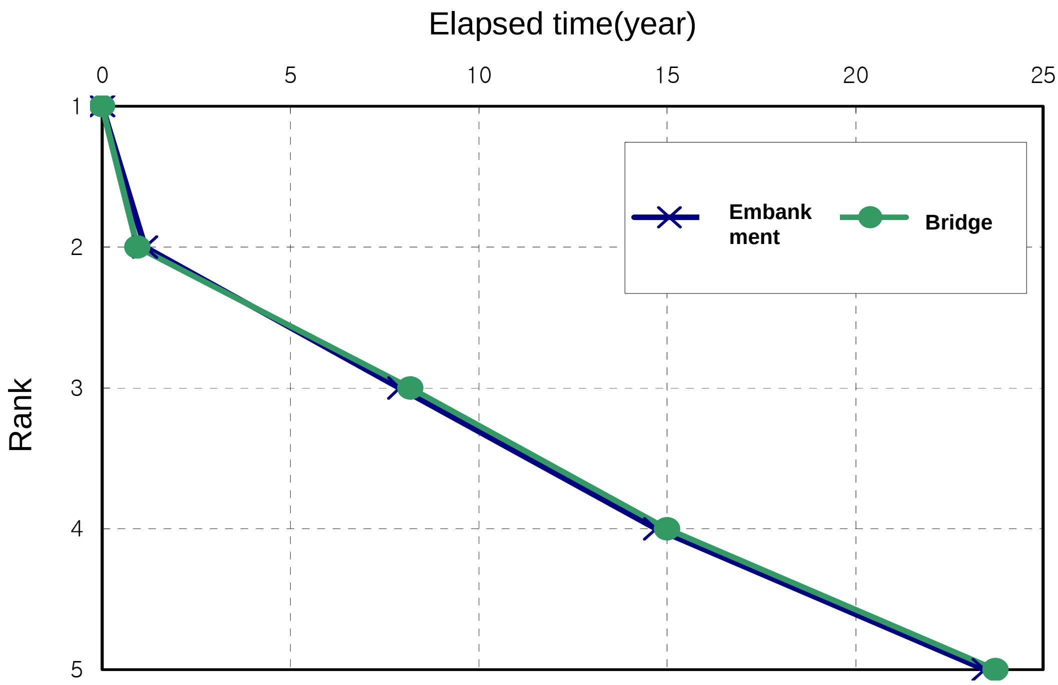

Figure-5. Performance curve of structure

5.3 Each Lane

Figure-6 compares performance curves for each lane. Since there are few samples for slower lane, deterioration speeds were compared between first lane, second lane and passing lane.

The following results were obtained.

- #5 The deterioration speed of ranks 1 to 2, 3 to 4, and 4 to 5 in the first lane is the fastest.
- #6 The deterioration tendency for the second lane and the passing lane seems similar. Especially the deterioration speed of ranks 3 to 4 and 4 to 5 is the same.
- #7 The first lane takes 17 years to reach rank 5, the second lane takes 34 years, and the passing lane takes 38years.

The reason for #5 is that many of cars with heavy wheel loads run in the first lane.
Although the order of deterioration speeds between the three lanes is considered appropriate, life span for each lane seems longer than it is observed from the past experiences.

	rank	1→2	2→3	3→4	4→5	Total
Life expectancy (year)	first lane	0.66	5.90	4.87	5.61	17.04
	second lane	1.11	5.50	9.66	17.64	33.91
	passing lane	1.64	8.95	9.66	17.64	37.89

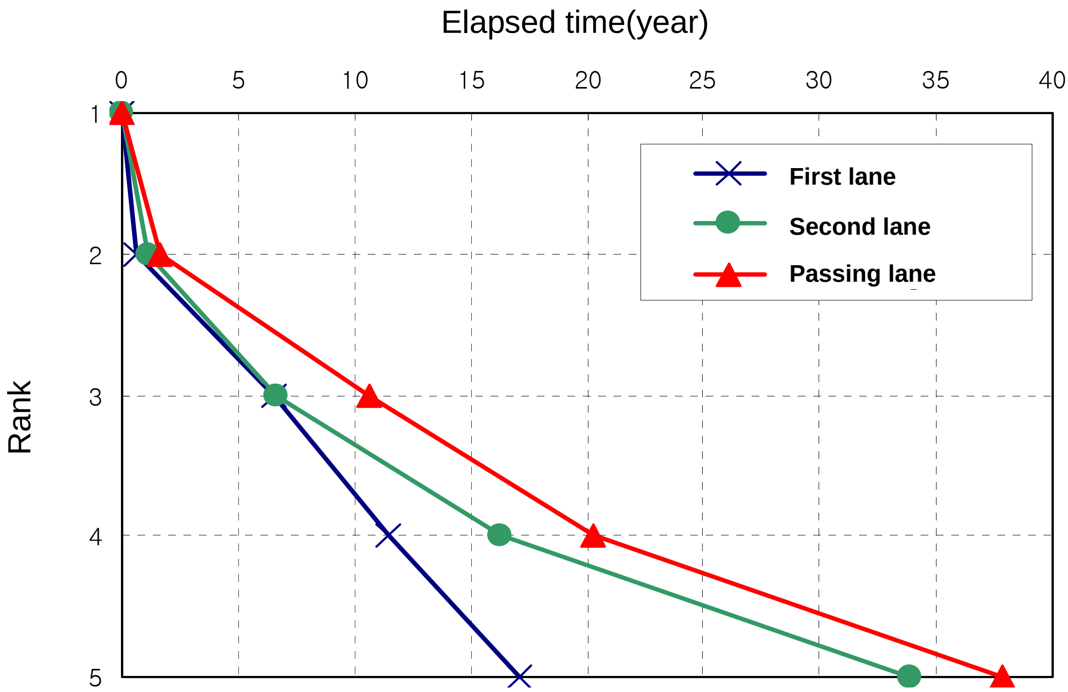

Figure-6. Performance curve of Lane classification

6. SUMMARY

In this paper, based on the rutting data and repair history, applicability of rutting forecasting model for a network level was evaluated. To evaluate applicability of rutting forecasting model, the factors that influence the process of deterioration were analyzed and commented. A rutting forecasting model was developed using a multi-stage exponential hazard model combing Markov transition probability.

As a result, lane classification influences a rutting increase speed.

However some problems are revealed in developing a rutting forecasting model due to decrease of data sample especially at ranks 4 and 5.

The reason of the decrease will inevitably arise from practical repair procedures for every project. For example in a repair project site that usually consists of several 100m length, rutting level will vary at different ranks; most of 100m site sections have rutting level at rank 5 while some have rank3. This is one of the reasons why data is decreased at higher rank levels.

In order to avoid this problem, a new rutting forecasting model is now being developed in consideration of compensating the decrease of sample from every project.

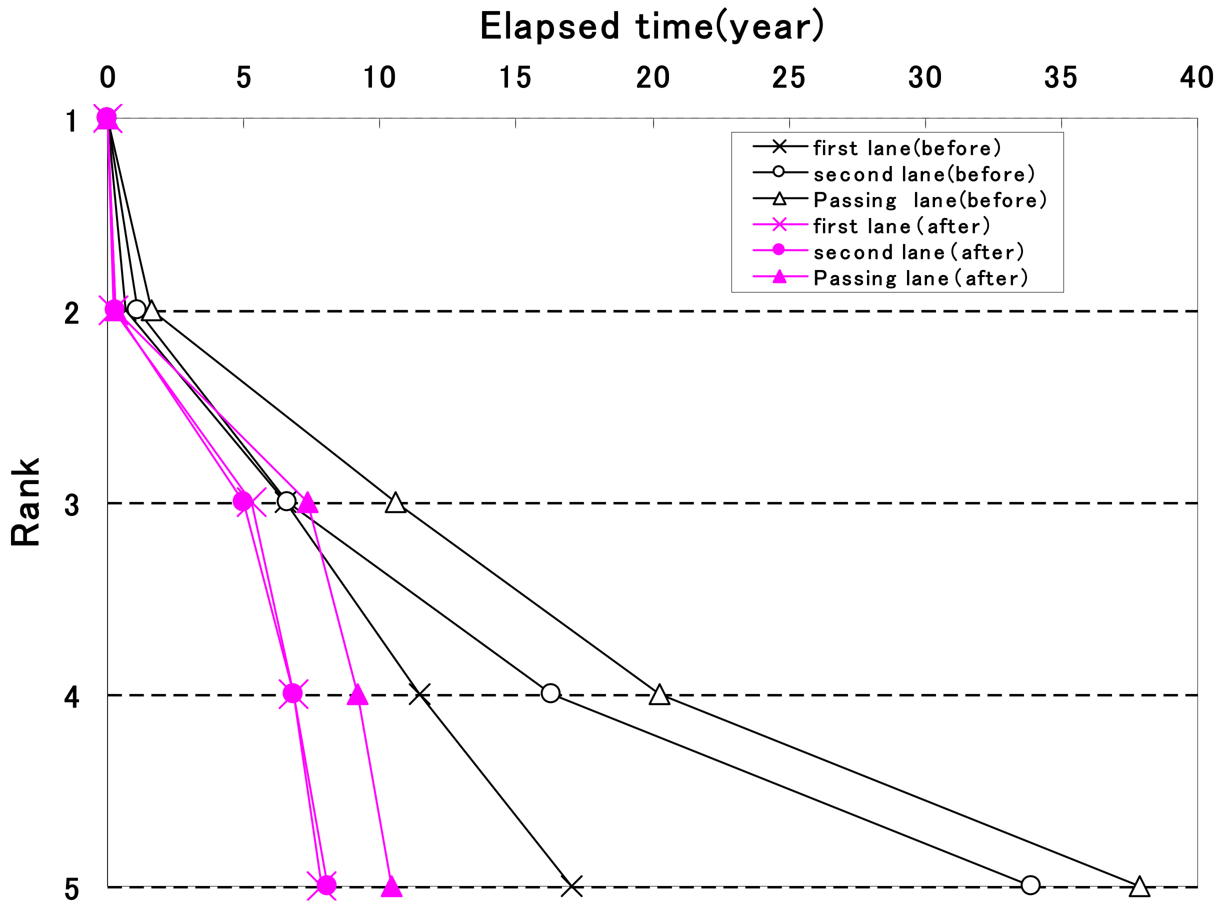

Figure-7. Performance curve of each lane before and after a new model

Figure-7 is a result of applying the new model at present. The following results were obtained.

- #8 The performance curve has changed greatly in "Before" and "After". There is quite difference in elapsed time between ranks 3 and 5.
- #9 The deterioration speed of rank 1 to 2, 3 to 4, and 4 to 5 in the first lane (after) is the earliest.
- #10 The deterioration tendency for the first lane (after) and the second lane (after) is similar.
- #11 The time that reaches rank 5 is 10 years in passing lane (after), while that for the first and second lane (after) is 8years.

In this way the current rutting forecast model for Kanetsu Expressway seems to be much reliable from road operator's view. This new model is going to apply to another route nearby.

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